SUPPLEMENT

TO BRITISH TELECOMMUNICATIONS ENGINEERING

(formerly the Supplement to The Post Office Electrical Engineers' Journal)

Vol. 1 Part 2 **July 1982**

ISSN 0262-4028

TEC & SCOTEC GUIDANCE FOR STUDENTS

Contents

TEC: ELECTRICAL PRINCIPLES II 33
TEC: TELECOMMUNICATIONS SYSTEMS I 36
SCOTEC: DIGITAL TECHNIQUES AND TRANSMISSION (1981) 39
SCOTEC: ELECTRICAL PRINCIPLES III (1981) 42
SCOTEC: MATHEMATICS III (1981) 45

TECHNICIAN EDUCATION COUNCIL

Certificate Programme in Telecommunications

Sets of model questions and answers for Technician Education Council (TEC) units are given below. The model questions and answers reflect the types and standards of questions that may be set by colleges and answers expected, and include the styles of both in-course and end-of-unit assessments. The model questions and answers therefore illustrate the assessment procedures that students may encounter, and are useful as practise material for the skills learned during the course.

The use of calculators is permitted except where otherwise indicated.

Representative time limits or proportion of marks are sometimes shown for each question, and care has been taken to give model answers that reflect these limits. Where additional text is given for educational purposes, it is shown within square brackets to distinguish it from the information expected of students under examination conditions.

We would like to emphasise that the model questions are not representative of questions set by any particular college.

ELECTRICAL PRINCIPLES II

Students are advised to read the notes above

The absolute permittivity of free space, ϵ_0, is $8 \cdot 854 \times 10^{-12}$ F/m, and the absolute permeability of free space, μ_0, is $4\pi \times 10^{-7}$ H/m.

Throughout this set of model answers, amperes/metre (A/m) are used as units of magnetic field strength, and amperes (A) are used for magnetomotive force. However, students may encounter, in some textbooks, the use of ampere-turns/metre (At/m) for magnetic field strength and ampere-turns (At) for magnetomotive force.

Q1 *Calculate the current flowing through R6 in Fig. 1.* *(12 min)*

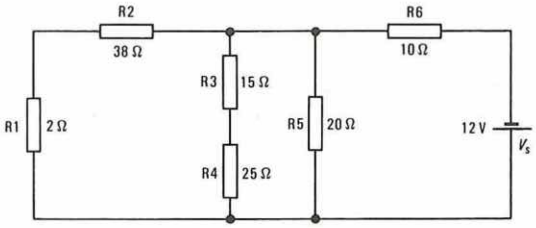


Fig. 1

A1 The equivalent resistance, R_7, of resistors R1 and R2 in series is given by

$$R_7 = R_1 + R_2 = 2 + 38 = 40\ \Omega.$$

The equivalent resistance, R_8, of resistors R3 and R4 in series is given by

$$R_8 = R_3 + R_4 = 15 + 25 = 40\ \Omega.$$

Therefore, the total resistance, R_9, in series with R6 is given by

$$\frac{1}{R_9} = \frac{1}{R_7} + \frac{1}{R_8} + \frac{1}{R_5} = \frac{1}{40} + \frac{1}{40} + \frac{1}{20} = \frac{4}{40} = \frac{1}{10}.$$

$$\therefore \quad R_9 = 10\ \Omega.$$

The total resistance in the circuit is given by

$$R_9 + R_6 = 10 + 10 = 20\ \Omega.$$

Therefore, the current flowing in R6 is given by

$$\frac{V_S}{R_9 + R_6} = \frac{12}{20} = \underline{0 \cdot 6\ \text{A}}.$$

Q2 *Calculate the current flowing in R2 in Fig. 2.* *(15 min)*

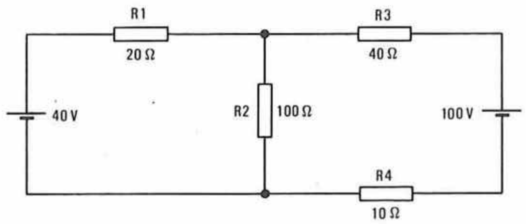
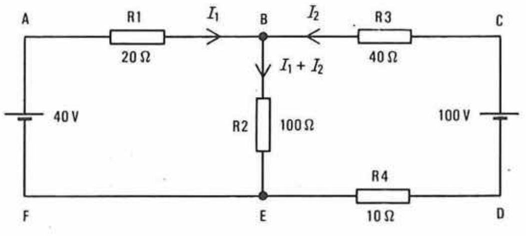


Fig. 2

A2 Applying Kirchhoff's first law, let the currents in the circuit loops be as shown in the sketch.



Applying Kirchhoff's second law to loop ABEF,

$$40 = 20I_1 + 100(I_1 + I_2).$$

$$\therefore \quad I_2 = \frac{40 - 120I_1}{100}. \qquad \ldots\ldots (1)$$

Applying Kirchhoff's second law to loop BCDE,

$$100 = 100(I_1 + I_2) + (10 + 40)I_2.$$

$$\therefore \quad 100 = 100I_1 + 150I_2. \qquad \ldots\ldots (2)$$

Substituting for I_2 (from equation 1) in equation 2,

$$100 = 100I_1 + 150\left(\frac{40 - 120I_1}{100}\right).$$

By simplifying the above equation,

$$100 = (100 - 180)I_1 + 60.$$

$$\therefore \quad I_1 = -\left(\frac{100 - 60}{80}\right),$$

$$= -0{\cdot}5\ \text{A}.$$

Substituting for I_1 in equation 1,

$$I_2 = \frac{40 + 60}{100},$$

$$= 1\ \text{A}.$$

Therefore, the current flowing in R2

$$= 1 - 0{\cdot}5,$$

$$= \underline{0{\cdot}5\ \text{A (in the direction shown in the sketch).}}$$

Q3 In which of the following situations will an electrostatic force of repulsion exist?

(*a*) *Two charged bodies each at opposite and equal potentials.*

(*b*) *Two charged bodies each at the same potential.*

(*c*) *Two uncharged bodies each at zero potential with respect to earth.*

(*d*) *Two charged bodies one at positive potential the other at earth potential.* (*2 min*)

A3 (*b*).

Q4 Calculate the charge in coulombs on the parallel plates of a capacitor, each plate having a surface area on one side of 10^4 mm², when the electric flux density between the plates is 20 μC/m². (*5 min*)

A4 The electric flux density, D, is given by

$$D = \frac{Q}{A}\ \text{coulombs/metre}^2,$$

where Q is the charge (coulombs) on the plates and A is the surface area (metres²).

$$\therefore \quad Q = AD,$$

$$= 10^4 \times 10^{-6} \times 20 \times 10^{-6},$$

$$= \underline{0{\cdot}2\ \mu\text{C}.}$$

Q5 Calculate the charge stored by a parallel plate capacitor if the area of each plate is 0·01 m² and the potential difference between them is 500 V. The plates are separated by a 0·1 mm thick dielectric whose relative permittivity is 2·5. (*7 min*)

A5 $E = \dfrac{V}{d} = \dfrac{500}{0{\cdot}1 \times 10^{-3}} = 5 \times 10^6$ V/m.

$$D = \epsilon_0\epsilon_r E = 8{\cdot}854 \times 10^{-12} \times 2{\cdot}5 \times 5 \times 10^6 = 111\ \mu\text{C/m}^2.$$

$$Q = DA = 111 \times 10^{-6} \times 0{\cdot}01 = \underline{1{\cdot}11\ \mu\text{C}.}$$

E: electric field strength
V: potential difference
d: distance between the plates
D: flux density

A: area of plates
ϵ_0: permittivity of free space
ϵ_r: relative permittivity

Q6 Calculate the capacitance of a parallel plate capacitor whose 2 plates each have a surface area on one side of 0·02 m² and are separated by a 0·01 mm thick dielectric of relative permittivity 2. (*5 min*)

A6 The capacitance, C, is given by

$$C = \frac{\epsilon_0\epsilon_r A}{d}\ \text{farads},$$

where ϵ_0 is the absolute permittivity of free space, ϵ_r is the relative permittivity of the dielectric, A is the area (square metres) of each plate, and d is the distance (metres) between the plates.

$$\therefore \quad C = \frac{8{\cdot}854 \times 10^{-12} \times 2 \times 0{\cdot}02}{0{\cdot}01 \times 10^{-3}},$$

$$= \underline{35{\cdot}416\ \text{nF}.}$$

Q7 Calculate the total energy stored by the capacitors in Fig. 3. (*12 min*)

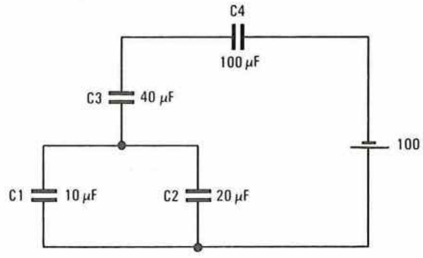


Fig. 3

A7 The equivalent capacitance, $C_{1//2}$, of C1 and C2 in parallel

$$= C_1 + C_2 = 30\ \mu\text{F}.$$

The total capacitance in the circuit, C_{tot}, is given by

$$\frac{1}{C_{\text{tot}}} = \frac{1}{C_{1//2}} + \frac{1}{C_3} + \frac{1}{C_4},$$

$$= \frac{1}{30 \times 10^{-6}} + \frac{1}{40 \times 10^{-6}} + \frac{1}{100 \times 10^{-6}},$$

$$= (3{\cdot}333 + 2{\cdot}5 + 1) \times 10^4,$$

$$= 6{\cdot}833 \times 10^4.$$

$$\therefore \quad C_{\text{tot}} = 14{\cdot}635\ \mu\text{F}.$$

The energy, W, stored in a capacitor is given by

$$W = \tfrac{1}{2}CV^2\ \text{joules},$$

where C is the capacitance (farads) and V is the voltage (volts).

Therefore, the total energy stored by the capacitors

$$= \tfrac{1}{2} \times 14{\cdot}635 \times 10^{-6} \times 100^2,$$

$$= \underline{73{\cdot}2\ \text{mJ}.}$$

Q8 Which of the following statements defines magnetising force?

(*a*) *The magnetomotive force required to maintain a magnetic flux.*

(*b*) *The magnetomotive force per unit length required to maintain a magnetic flux at a fixed point.*

(*c*) *The amount of magnetic flux passing through an area of 1 m² whose plane is perpendicular to the direction of flow.*

(*d*) *The magnetic force required to generate an EMF of 1 V by a flux of 1 Wb.* (*3 min*)

A8 (*b*).

Q9 Use the values given in Table 1 to calculate the current required to maintain a magnetic flux density of 5 T in the air gap of the magnetic circuit shown in Fig. 4. (*20 mins*)

Table 1—B/H relationship for the ring shown in Fig. 4.

Field strength, H (A/m)	*1000*	*2000*	*3000*	*4000*	*5000*	*6000*
Flux density, B (T)	*2*	*4·2*	*5·6*	*6·6*	*7·3*	*8*

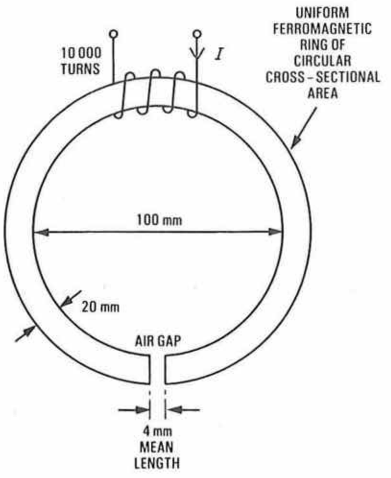
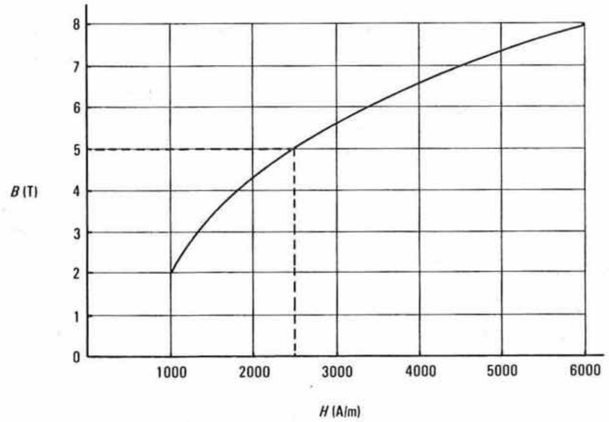


Fig. 4

A9 A graph of the values given in Table 1 is shown in the sketch.



For the air gap,

$$H_a = \frac{B}{\mu_o \mu_r} = \frac{5}{1 \times 4\pi \times 10^{-7}} = 3{\cdot}979 \times 10^6 \text{ A/m}.$$

Also, $$H_a = \frac{MMF_a}{l_a}.$$

$\therefore \quad MMF_a = H_a l_a = 3{\cdot}979 \times 10^6 \times 4 \times 10^{-3} = 15\,916$ A.

From the plotted graph, $H_{ring} = 2500$ A/m.

Therefore, the MMF required for the ring, MMF_{ring},

$= H_{ring} \times l_{ring} = 2500 \times (120 \times 10^{-3}\pi - 4 \times 10^{-3}) = 932$ A.

The total MMF, MMF_{tot}, required to maintain a flux density of 5 T

$= MMF_a + MMF_{ring} = 15916 + 932 = 16\,848$ A.

The current required

$$= \frac{MMF_{tot}}{N} = \frac{16\,848}{10\,000} = \underline{1{\cdot}68 \text{ A.}}$$

H: field strength
MMF: magnetomotive force
l: length of magnetic circuit
N: number of turns on coil
B: flux density
μ_o: absolute permeability of free space
μ_r: relative permeability
a: air gap

Q10 *Calculate the force on a coil of 200 turns carrying a current of 4 A situated in a magnetic field of flux density 0·2 T as shown in Fig. 6.* *(5 min)*

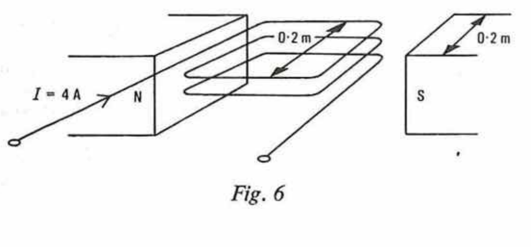


Fig. 6

A10 The force on the coil, F, is given by

$$F = BlI \text{ newtons},$$

where B is the flux density (tesla), l is the length of the conductor (metres) cutting the magnetic field and I is the current (amps) flowing in the conductor.

$$\therefore \quad F = 0{\cdot}2 \times (0{\cdot}2 \times 2 \times 200) \times 4,$$
$$= \underline{64 \text{ N.}}$$

Q11 *For the hysterisis loop shown in Fig. 5, state the values of*

(*a*) *saturation flux density,*
(*b*) *coercivity, and*
(*c*) *remanence.* *(5 min)*

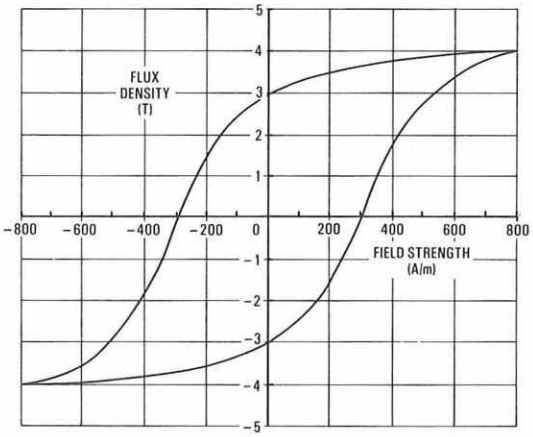


Fig. 5

A11 (*a*) 4 T
(*b*) 300 A/m
(*c*) 3 T

Q12 *Calculate the reluctance of a magnetic circuit with a cross-sectional area of 0·001 m², and which is wound with 100 turns of wire carrying a current of 2 A, if the flux density in the circuit is 0·2 T.* *(7 min)*

A12 $$S = \frac{MMF}{\Phi} \text{ henrys}^{-1}.$$

$$\Phi = BA = 0{\cdot}2 \times 0{\cdot}001 = 200\ \mu\text{Wb}.$$

Also, $$MMF = IN = 2 \times 100 = 200 \text{ A}.$$

$$\therefore \quad S = \frac{200}{2 \times 10^{-4}} = \underline{1 \times 10^6 \text{ H}^{-1}.}$$

S: reluctance
B: flux density
MMF: magnetomotive force
Φ: flux
I: current
N: turns on coil
A: cross-sectional area

Q13 (*a*) *Calculate the EMF induced in a coil of inductance 1 mH when the current in the coil changes from 1 A to 0·5 A in 20 μs.* *(5 min)*
(*b*) *Calculate the energy released by the coil in part* (*a*). *(6 min)*

A13 (*a*) The EMF, E, induced in a coil is given by

$$E = -L\frac{dI}{dt},$$

where L is the inductance (henrys) and dI/dt is the rate of change of current.

$$\therefore \quad E = \frac{1 \times 10^{-3} \times (1 - 0{\cdot}5)}{20 \times 10^{-6}} = \underline{25 \text{ V.}}$$

(*b*) The energy released, W_r

= energy stored before change − energy stored after change.

If I_i and I_f are the initial and final values of the current, then,

$$W_r = \tfrac{1}{2}LI_i^2 - \tfrac{1}{2}LI_f^2,$$
$$= \frac{1 \times 10^{-3}}{2}(1 - 0{\cdot}25) = \underline{375\ \mu\text{J.}}$$

TELECOMMUNICATIONS SYSTEMS I

Syllabus TEC U81/748 (Revised). Students are advised to read the notes on page 33

Q1 (a) State 2 media that are used for the transmission of information by electrical means.

(b) For each of the above media, state a communication system that uses that media to a great extent. (4 marks)

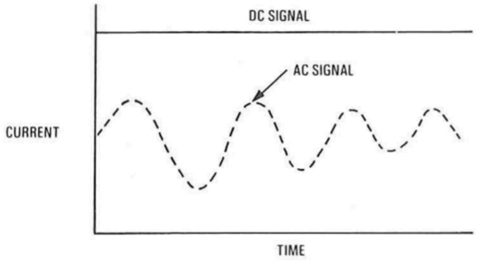
A1 (*a*) Cables (wires) and free space (air).

(*b*) Cables—telephone system.
Free space—radio and television systems.

Q2 (a) Sketch a graphical representation of 2 electrical signals to illustrate the difference between AC and DC signals. Suitably label your answer.

(b) Give a practical example of where a DC signal is used, and state any problems when this type of signalling system is used. (5 marks)

A2 (*a*)



[*Tutorial note:* The shape of the AC signal may be different but it should vary about a mean point.]

(*b*) Bell, lamp, fuel gauge, telephone dial etc.
[*Tutorial note:* There are many examples of DC signalling; any of the above would be acceptable.]
Limitations of this type of system are:

(*i*) distance and the problems of high currents and signal regeneration, and
(*ii*) distortion caused by the characteristics of the circuit or line.

Q3 State all the characteristics of a signalling tone that determine

(a) its loudness, and

(b) its pitch. (4 marks)

A3 (*a*) The loudness of a tone is determined by its amplitude.

(*b*) The pitch of a tone is determined by its frequency (wavelength or period).

Q4 Fig. 1 shows the graphical representation of an analogue speech signal that leaves a local battery telephone. Draw the shape of the equivalent speech sound wave. (4 marks)

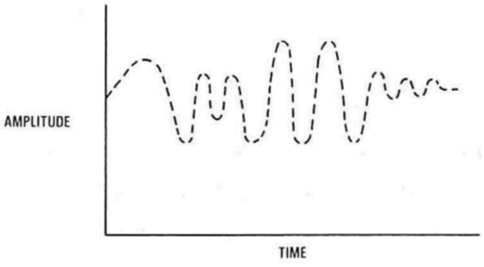


Fig. 1

A4 Because this is an analogue signal, the sound pressure wave has an identical shape to the electrical wave.

Q5 Which of the following is the speech carrier that is modulated in a local battery telephone system?
(a) Transmitter
(b) Battery current
(c) Induction coil
(d) Line

A5 (*b*).
[*Tutorial note:* The action of the transmitter is to vary the current that passes through it; thus the steady battery current acts as the carrier, which is modulated by the transmitter.]

Q6 Name 2 types of transducers that are used in a local battery telephone system, and state the function of each type. (4 marks)

A6 Two types of transducers are:

(*a*) The transmitter. The function of the transmitter is to convert sound energy waves into electrical energy waves.
(*b*) The receiver. The function of the receiver is to convert the electrical waves back into sound waves.

Q7 If the magnetic field strength of the permanent magnet in a rocking armature receiver were doubled, would the output from the receiver be
(a) doubled,
(b) halved,
(c) unchanged, or
(d) reduced to nothing? (2 marks)

A7 (*c*).

Q8 What is the frequency of a sinusoidal wave if the period of one cycle is 4 ms? (2 marks)

A8
$$\text{Frequency} = \frac{1}{\text{Period}} = \frac{1}{4 \times 10^{-3}} = \frac{1000}{4},$$
$$= \underline{250\ \text{Hz.}}$$

Q9 If the wavelength of a signal doubles, does the frequency of the signal
(a) halve,
(b) not change,
(c) double, or
(d) change in some other way? (2 marks)

A9 (*a*).

[*Tutorial note:* $\text{Frequency} \propto \dfrac{1}{\text{Wavelength}}.$

Therefore, if the wavelength is doubled then the frequency is halved.]

Q10 (a) State the 3 functional types of Telex exchange in use in the UK.
(b) Which of these exchanges are fully interconnected with ALL other exchanges of the same type? (3 marks)

A10 (*a*) (*i*) Area exchange
(*ii*) Zone exchange
(*iii*) International switching centre exchange

(*b*) All zone exchanges are fully interconnected.

Q11 The following components are used to link a telephone to a local exchange; indicate their correct order from the subscriber and the type of distribution cables used in these links.

Components	*Order*
Secondary cross-connection point (SCCP)	
Primary cross-connection point (PCCP)	
Distribution point (DP)	
Main distribution frame (MDF)	

Type of Link	*Type of Cable*
.... *to*	.... *distribution cable*
.... *to*	.... *distribution cable*
.... *to*	.... *distribution cable*

(6 marks)

A11

Component	Order
SCCP	2
PCCP	3
DP	1
MDF	4

Type of Link	Type of Cable
DP to SCCP	Local distribution cable
SCCP to PCCP	Branch distribution cable
PCCP to MDF	Main distribution cable

Q12 Without using transit centres, list all the telephone exchanges that might be used in linking a subscriber in outer London to a subscriber who is midway between Edinburgh and Glasgow. Indicate the numbers and types of exchanges.

	Type of Exchange	*Number of Exchanges*
London Subscriber		
Scottish Subscriber		

(*5 marks*)

A12

	Type of Exchange	Number of Exchanges
London Subscriber	Local exchange	1
	Group switching centre	Maximum of 3
Scottish Subscriber	Local Exchange	1

Q13 Which of the following types of character signalling is used in a teleprinter?

(*a*) *Single current*

(*b*) *Double current*

(*c*) *Loop-disconnect*

(*d*) *Amplitude modulation* (*1 mark*)

A13 (*b*).

Q14 Complete the trunking diagram shown in Fig. 2 by inserting the missing links between the 2 telephones. Ensure that all the links are correctly positioned at each point. (*5 marks*)

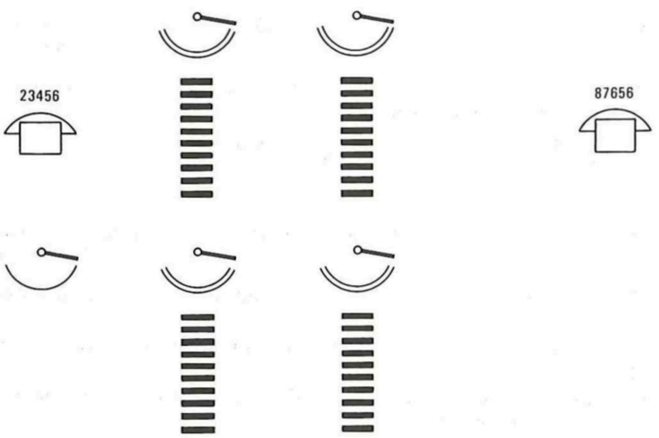
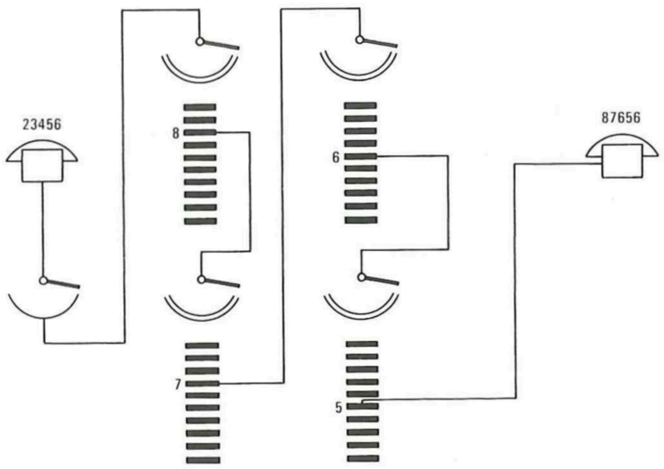


Fig. 2

A14



[*Tutorial note:* All connections to switching banks should be shown at the end of the bank arc, except for the final selector where it should be shown in the centre of the bank arc.]

Q15 What is the maximum number of simultaneous calls that a switch matrix can handle if it has a total of 22 outlets and 264 crosspoints?

(*a*) *10* (*b*) *12* (*c*) *22* (*d*) *264* (*2 marks*)

A15 (*b*).

[*Tutorial note:* The total number of inlets $= \frac{264}{22} = 12$.

Therefore, a maximum of 12 simultaneous calls can be handled by this matrix.]

Q16 (*a*) *Give a short explanation of the principle difference between a common-control exchange and a Strowger exchange.*

(*b*) *Give one advantage that this difference gives to a common-control exchange.* (*4 marks*)

A16 (*a*) In a common-control exchange all the dialled digits go into a central store, and from this the complete route through the exchange is determined. In a Strowger exchange each dialled digit determines just one part of the route through the exchange, step-by-step.

(*b*) Because of this difference, the common-control exchange has the advantage that it can offer repeat attempts at finding a free route through the exchange.

Q17 If 2 computers are connected together over a standard telephone line where should the modems be connected. (*2 marks*)

A17 The modems must be installed at each end of the telephone line just before it is connected to any computer terminal equipment.

Q18 List 4 computer input/output devices, and state one advantage that each device has over the others. (*2 marks*)

A18 (*a*) Teletype. This gives printed record of input and output.

(*b*) Punch card. This allows pre-recorded input off line.

(*c*) Magnetic tape. This allows reusable pre-recorded input with flexible updating.

(*d*) Visual display unit (VDU) and keyboard. This gives immediate input and output without the waste of paper.

Q19 State why data signals cannot be conveyed directly over the existing telephone network. (*3 marks*)

A19 Many telephone connections consist of a number of components which do not allow the passage of the DC data pulses; for example, transmission bridges, line amplifiers, frequency division multiplex (FDM) equipment, signalling units, long sections of audio cable.

Q20 Indicate by ticking the appropriate box the type of signal expected between the following points on a Datel circuit.

	Tick (√) appropriate box	
	Digital	*Analogue*
Computer Terminal – Modem		
Telephone – Telephone		
Modem – Modem		
Modem – Computer Terminal		
Telephone – Computer Control Centre		

(*5 marks*)

A20

	Digital	Analogue
Computer Terminal – Modem	√	
Telephone – Telephone		√
Modem – Modem		√
Modem – Computer Terminal	√	
Telephone – Computer Control Centre		√

Q21 State the main functional differences between a commercial communication radio system and a commercial broadcast system. (*2 marks*)

A21 Communication radio systems give

(*a*) 2-way communication, and
(*b*) point-to-point communication.

Broadcast systems give

(*a*) mainly one-way communication, and
(*b*) communication from one central point to many receivers within range.

Q22 State the fundamental difference between materials that reflect radio waves to those that allow them to pass through. (*2 marks*)

A22 Metallic or electrically conducting materials reflect radio waves, and electrically insulating materials allow radio waves to pass through.

Q23 At what frequency can radio waves begin to penetrate through the ionosphere. State the term used to describe these waves. (*2 marks*)

A23 Radio waves can penetrate the ionosphere at 30 MHz and above; these are called space waves.

Q24 To establish a 2-way telephony conversation, which of the following is required?

(*a*) *Two transmitters and 2 receivers working at the same frequency.*
(*b*) *One transmitter and one receiver working at the same frequency.*
(*c*) *Two transmitters working at different frequencies and 2 receivers working at the same different frequencies.*
(*d*) *One transmitter and one receiver working at different frequencies.* (*1 mark*)

A24 (*c*).
[*Tutorial note:* The important point here is that for 2-way radio telephony 2 different transmitting frequencies are necessary, one for each direction of transmission.]

Q25 Explain briefly what is meant by the term scanning when applied to

(*a*) *a television camera, and*

(*b*) *a television receiver.*

Highlight any significant difference. (*4 marks*)

A25 (*a*) Scanning in a television (TV) camera is the process whereby light sensitive components in the camera are interrogated sequentially to determine the amount of light entering the camera and thereby an electrical representation of the image seen by the camera is built up.

(*b*) In a similar sequence, the TV receiver scans the screen with an electron beam causing the screen to illuminate in direct response to the pattern built up within the TV camera. Instead of building up the complete picture in one scan, it is necessary to carry out 2 scans to complete the picture.

Q26 (*a*) *Select the correct statement from the following.*
The quality of a TV picture can best be improved

(*i*) *by providing a few more picture lines,*
(*ii*) *by making the picture lines more closely interleaved,*
(*iii*) *by increasing the scanning rate, or*
(*iv*) *by increasing the persistence of the screen.*

(*b*) *Give the main reason for adopting the current quality standard.* (*4 marks*)

A26 (*a*) (*i*).
[*Tutorial note:* The current British standard for ultra-high frequency (UHF) transmissions is 625 lines for a complete picture; this gives an improvement in picture quality over the older very-high frequency (VHF) standard of only 405 lines.]

(*b*) Cost.
[*Tutorial note:* The current standard is judged to be a reasonable economical standard. Any significant improvement would require a disproportionate increase in costs.]

Q27 (*a*) *Describe briefly what Ceefax and Oracle are.*

(*b*) *What is the main difference between them?* (*4 marks*)

A27 (*a*) Ceefax and Oracle are the trade names given to the broadcast teletext services provided by the British Broadcasting Corporation (BBC) and the Independant Broadcasting Authority (IBA).

(*b*) They are technically similar; Ceefax is the BBC service, and Oracle the IBA service.

Q28 State the target measurements that can be made by using primary radar. (*3 marks*)

A28 (*a*) Range,
(*b*) bearing, and
(*c*) height

Q29 (*a*) *State the frequency range with which primary radar is operated in the UK.*

(*b*) *State the frequency range with which secondary radar is operated in the UK.* (*2 marks*)

A29 (*a*) 3–10 GHz.
[*Tutorial note:* G = Giga = 10^9.]

(*b*) Secondary radar operates in the same frequency range as primary radar and responds by sweeping through the complete range.

Q30 Give 2 advantages that secondary radar have over primary radar. (*2 marks*)

A30 (*a*) When it operates over similar distances, secondary radar requires less power than primary radar.

(*b*) Secondary radar transmits an identity code to allow positive identification by the receiver.

Q31 State 4 main differences between the Prestel service and the broadcast teletext services. (*4 marks*)

A31 The differences between Prestel and the broadcast teletext services are:

(*a*) a user can interrogate the Prestel computers directly over a telephone line,

(*b*) a user can go to a wanted page directly without waiting for the particular page to appear,

(*c*) Prestel has a greater capacity, and

(*d*) messages can be interchanged on Prestel.

SCOTTISH TECHNICAL EDUCATION COUNCIL

Certificate in Electrical and Electronic Engineering

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DIGITAL TECHNIQUES AND TRANSMISSION 1981

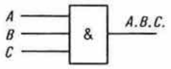
Students were expected to attempt all questions in Section A and 4 questions in Section B. This was a 3 h paper

SECTION A

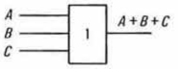
Q1 Define an AND and an OR gate and give their truth tables.

A1 An AND gate is the electronic equivalent of a number of switches connected in series; the gate is closed when all the switches are closed. The circuit has 2 or more inputs and one output.

An OR gate is the electronic equivalent of a number of switches connected in parallel; the gate is closed when any one or more of the switches is closed.



AND GATE



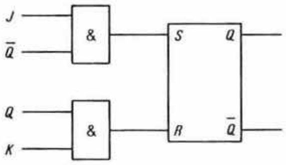
OR GATE

Inputs			Outputs	
A	B	C	$A.B.C.$	$A+B+C$
0	0	0	0	0
0	0	1	0	1
0	1	0	0	1
0	1	1	0	1
1	0	0	0	1
1	0	1	0	1
1	1	0	0	1
1	1	1	1	1

[*Tutorial note:* Truth tables for only 2 inputs would be acceptable.]

Q2 Convert a SR bistable to a JK bistable.

A2



Q3 What is the advantage of a synchronous counter over a ripple counter?

A3 A synchronous counter is faster than a ripple-through counter and, since the outputs of the counter change in synchronism with the input signal pulses, a synchronous counter cannot be misread.

Q4 Explain how a ferrite core can be used to store information.

A4 A ferrite core can be used to store information by magnetising it. When the ferrite core is magnetised with one particular polarity it represents state 0, and when it is magnetised with the opposite polarity it represents state 1. It is magnetised by passing a current through a wire threading the core.

Q5 Describe briefly the basic principle of a facsimile telegraphy system.

A5 Facsimile telegraphy is the transmission and reception of still pictures, diagrams etc. The picture that is to be transmitted is mounted on a circular drum which is threaded onto a lead screw, so that one revolution of the screw moves the drum the pitch of the screw. A light is focussed on to the drum and illuminates a small area of the picture; as the drum rotates the whole picture is progressively scanned. The light reflected from the picture is focussed onto a photo-electric cell, and fluctuates in sympathy with the picture density; a fluctuating voltage is produced from the photo-electric cell, and this signal is used as the signal voltage. The frequency of the output signal is in the range 0–550 Hz say, and so it can be readily transmitted along an audio line. At the receiving end a fluctuating light moves over sensitive film or paper in synchronism with the received signal to reproduce the original.

Q6 Compare double- and single-current working and give any advantage one has over the other.

A6 Single-current working refers to the system where the telegraph signals are formed by switching a steady voltage ON and OFF in accordance with a code.

Double-current working is where the telegraph signals are formed by reversing the polarity of the steady voltage.

Where double-current working is used, pulse distortion and interference are reduced, sensitivity is increased and the speed of transmission can be increased.

Q7 Describe briefly a method by which data may be transmitted over an audio circuit.

A7 Since DC components cannot be transmitted readily over an audio circuit, data can be transmitted by the use of frequency shift modulation at say 600 bit/s or 1200 bit/s by using a 1300 Hz tone for 1 and a 1700 Hz tone for 0, or a 1300 Hz tone for 1 and a 2100 Hz tone for 0.

Q8 What is meant by the term quantisation used in connection with pulse-code modulation?

A8 In pulse-code modulation, the amplitude of the signal is sampled and the amplitude measured is referred to one of a number of levels into which the amplitude range is divided. This level number is then coded into a sequence of binary digits, which is transmitted. The process of rounding the sampled values to the nearest level is termed quantisation.

Q9 What is a modem and for what is it used?

A9 A modem (*mo*dulator-*dem*odulator) is a device that is used to modulate and demodulate signals at either end of a data communication system; it enables digital signals to be sent over an analogue network.

Q10 Explain how a signal is attenuated due to losses in a cable.

A10 In all types of cable the conductors have some resistance. There is also some leakage resistance, which allows current to flow out of, instead of along, the conductors. Capacitance between conductors also provides a path for loss especially at high frequencies. All these losses of energy result in a signal being attenuated.

SECTION B

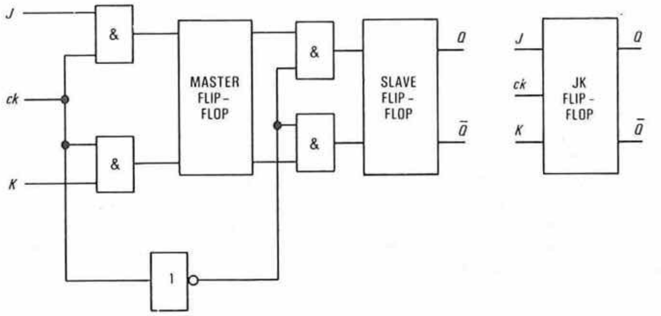
Q11 Draw a master-slave JK flip-flop system. Explain its operation and show that the race-around condition is eliminated.

A11 The circuit shown in the sketch is equivalent to the JK flip-flop in its operation. It is connected as a master-slave combination and operates as follows.

The master flip-flop A is triggered by the positive going 0–1 transition of the clock pulse and the slave flip-flop B is triggered by the later 1–0 transition that is changed to a positive going pulse by the inverter in the clock line to the slave circuit.

When the clock is at 0, the slave is fixed at the state of the master circuit. When the clock moves to 1, the slave flip-flop is locked and the master responds to the input states at J and K. When the clock goes from 1 to 0, the slave switches to the state of the master circuit.

The combined circuit overcomes the race-around difficulty since the slave is inhibited during the clock pulse ($\overline{ck} = 0$) and there is no feedback to cause extraneous triggering.



ck: CLOCK INPUT

Q12 (*a*) *Explain what is meant by frequency-shift keying and why only the first pair of side frequencies need be transmitted.*

(*b*) *What advantage does this give?*

(*c*) *What do you understand by the term phase-shifting keying?*

A12 (*a*) Frequency-shift keying (FSK) is used to transmit telegraphy signals by radio. For FSK the mark condition is at one carrier frequency and the space condition at another. The difference between the mark and space frequencies is in the audio range and is known as the *frequency shift*. The system can be regarded as a frequency modulation (FM) system which uses square-wave modulation, the carrier being deviated one way for the mark condition and the other way for the space condition. The signal can be detected by a normal FM demodulator.

Although square-wave modulation is used, the receiver need receive only the 2 frequencies; any harmonics are not required to reproduce the signal, hence only the first pair of side frequencies needs to be transmitted.

(*b*) This system can be used on radio circuits where there is only a narrow bandwidth; it can also be used on telephone lines. There are also advantages to be gained where there is fading or a high noise level.

(*c*) Phase-shift keying is the change of phase of a constant frequency carrier between 2 specified values. However, to demodulate this a suitable reference wave is required, and so this system is seldom used. Phase-modulated data systems use differential phase modulation, and changes in phase, rather than the phase angle itself, are used to indicate the binary digits.

Q13 (*a*) *What is meant by group delay and group delay/frequency distortion?*

(*b*) *Explain the effects that group delay/frequency distortion can have on a signal.*

(*c*) *Draw typical group delay/frequency characteristics for:*

(*i*) *an audio cable; and* (*ii*) *a loaded audio cable.*

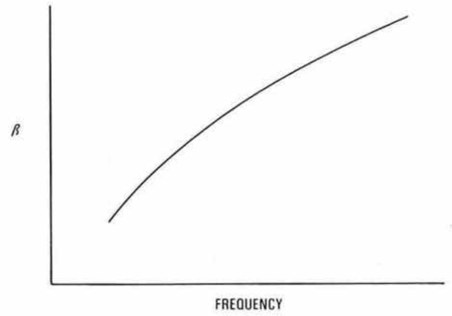
A13 (*a*) and (*b*) Each of the frequency components of a non-sinusoidal signal, which is transmitted along a line, travel with a phase velocity of ω/β metres/second, where ω (radians/second) is $2\pi \times$ frequency (hertz), and β (radians/metre) is the phase change coefficient. If β is a linear function of frequency (that is, ω/β is constant at all frequencies) then all the components arrive at the far end of the line at the same time and there is no distortion of the signal.

In an audio-frequency cable, β varies non-linearly with frequency as shown in sketch (*a*). Thus, if a signal has a fundamental and a third harmonic, as shown in sketch (*b*), then the phase velocity of the harmonic is greater than that of the fundamental, and so the signal is distorted, as shown in sketch (*c*).

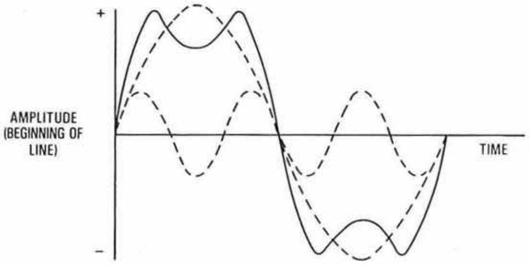
It is usual to consider the group velocity of a complex wave rather than the phase velocities of its individual components. Group velocity is the velocity at which the envelope of the resultant waveform is propagated. If a narrow band of frequencies in the range ω_2 to ω_1 is transmitted over a line, and the phase change coefficients are β_2 and β_1, respectively, the group velocity, V_g, is given by

$$V_g = \frac{\omega_2 - \omega_1}{\beta_2 - \beta_1} \text{ metres/second.}$$

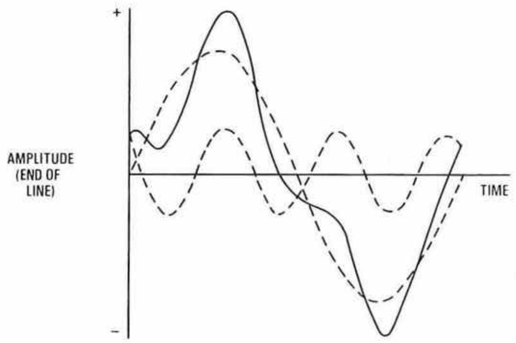
The group delay of a line is the product of the length of the line and the reciprocal of its group velocity.



(*a*)

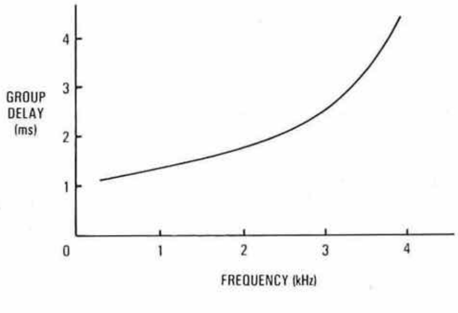


(*b*)

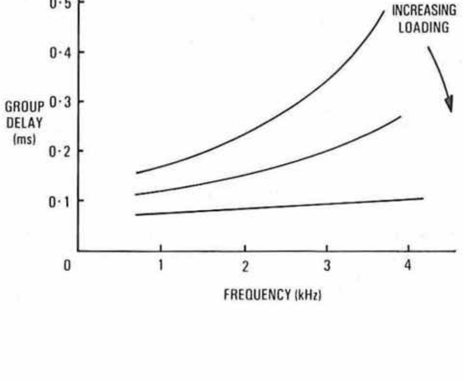


(*c*)

(*c*) (*i*)



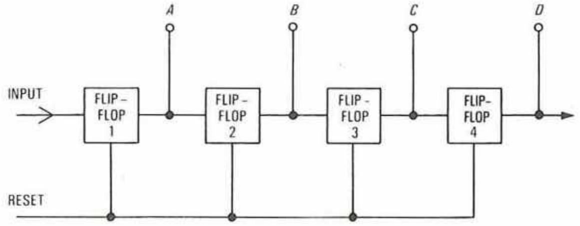
(*ii*)

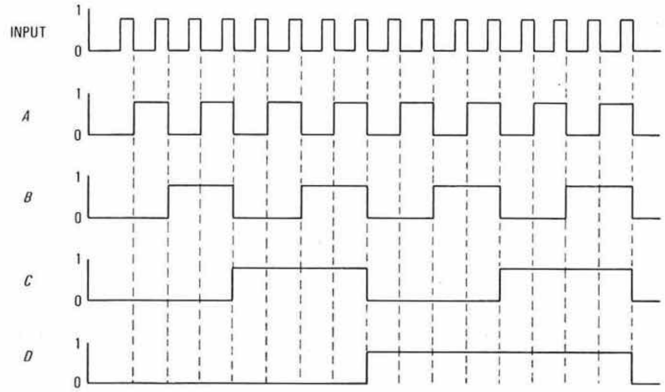


Q14 Draw a block diagram of a 4-stage binary asynchronous counter and show by the use of waveform diagrams the logic state of the output stages at the system time intervals.

Give a truth table to show the whole sequence of the operation of counter.

A14





Outputs				Number of Input Pulses
D	*C*	*B*	*A*	
0	0	0	0	0
0	0	0	1	1
0	0	1	0	2
0	0	1	1	3
0	1	0	0	4
0	1	0	1	5
0	1	1	0	6
0	1	1	1	7
1	0	0	0	8
1	0	0	1	9
1	0	1	0	10
1	0	1	1	11
1	1	0	0	12
1	1	0	1	13
1	1	1	0	14
1	1	1	1	15

[*Tutorial note:* Other similar circuits would be acceptable.]

Q15 (a) Explain how pulse-code modulation (PCM) is used to transmit a continuous signal waveform as a train of binary digits.

(b) What are the advantages and the disadvantages of PCM.

(c) What would be the minimum sampling frequency for a signal from say 300–3400 Hz, and what sampling frequency would be used?

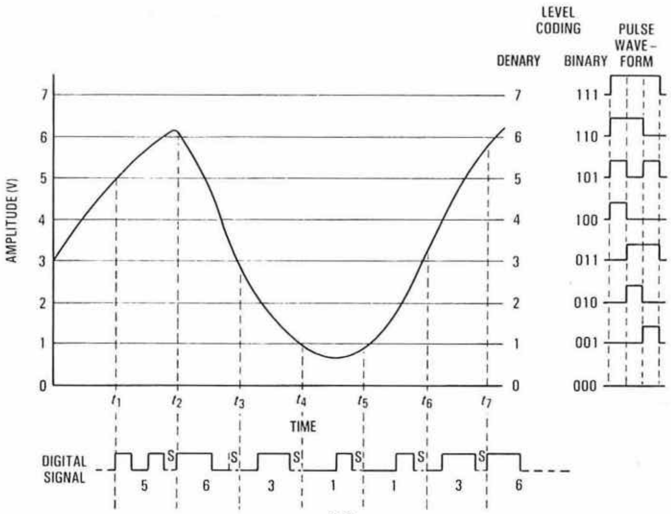
A15 (*a*) PCM can be used to transmit a continuous signal waveform as a sequence of binary digits by sampling the amplitude of the signal at intervals and then by coding the amplitude measured into a series of pulses according to the level. An example of this process is shown in sketch (*a*).

(*b*) PCM has good signal-to-noise ratio characteristics and, through the use of pulse regeneration, is well suited to long distance communication. However, PCM requires a large bandwidth, is complex, and is costly to implement.

(*c*) The minimum sampling frequency is

$$2 \times \text{(the maximum frequency transmitted)},$$
$$= 2 \times 3400,$$
$$= \underline{6800\text{ Hz.}}$$

A sampling frequency of 8 kHz would be used.



(*a*)

Q16 (a) Draw, and explain the action of logic circuits which perform the function

(i) OR, and (ii) AND.

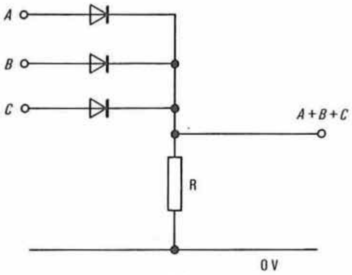
Clearly indicate polarities.

(b) Define positive logic.

(c) What is the main disadvantage of diode-resistor logic?

(d) Explain the terms fan-out and fan-in.

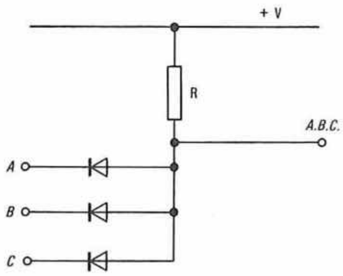
A16 (*a*) (*i*) A circuit diagram of an OR gate is shown in sketch (*a*). If any of the 3 input voltages are high (that is, $+V$ volts), then the associated diode conducts and there is a voltage drop across resistor R of approximately V volts. If all of the input voltages are low (that is, 0 V), then no diode conducts and the output is at 0 V.



(*a*)

(*ii*) A circuit of an AND gate is shown in sketch (*b*). If any of the input voltages are low (that is, 0 V), then the associated diode conducts and there is a voltage drop across resistor R of approximately V volts. Therefore, the voltage at the output is 0 V.

If all the input voltages are at $+V$ volts, then no diode conducts and a negligible voltage is dropped across resistor R. Therefore, the voltage at the output is $+V$ volts.



(*b*)

[*Tutorial note:* Other circuits would be acceptable.]

(*b*) In positive logic, the voltage assigned to the 1 state is more positive than that of the 0 state.

(*c*) The main disadvantage of diode-resistor logic is that the forward resistance of the diodes causes a voltage drop when it is conducting, and this reduces the high-voltage level and increases the low-voltage level; that is, low fan-out.

(*d*) Fan-out is a measure of the number of other gates that can be driven by one gate.

Fan-in of a logic gate is the number of inputs to the switch.

ELECTRICAL PRINCIPLES III 1981

Students were expected to attempt all questions in Section A and 4 questions from Section B. The time for the examination was 3 h

SECTION A

Q1 *Suggest and justify possible uses for the following magnetic materials*

(*a*) *alnico,*

(*b*) *mumetal, and*

(*c*) *silicon steel.*

A1 (*a*) Alnico could be used for a permanent magnet because it has high remanence.

(*b*) Mumetal is suitable for use in recording heads because of its linear magnetisation characteristic.

(*c*) Silicon steel could be used to form a relay core because it possesses high permanence.

Q2 *For the network shown in Fig. 1, what value of R would let it dissipate the maximum power?*

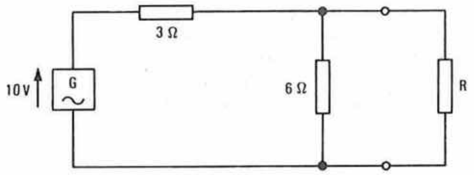


Fig. 1

A2 Maximum power is dissipated in the load resistor, R, when R is equal to the internal resistance, R_{int}, of the supply network.

$$R_{\text{int}} = \frac{3 \times 6}{3 + 6} = 2\ \Omega.$$

Therefore, for maximum power transfer, $R = \underline{2\ \Omega.}$

Q3 *State Kirchhoff's Voltage law.*

A3 Around any closed loop, the sum of the EMFs is equal to the sum of the voltage drops.

Q4 *For the network shown in Fig. 2, evaluate the resonant frequency.*

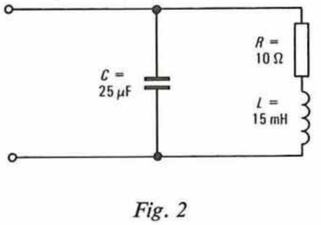


Fig. 2

A4 The resonant frequency of the circuit, f_r, is given by the expression

$$\frac{1}{2\pi}\left(\frac{1}{LC} - \frac{R^2}{L^2}\right)^{\frac{1}{2}}$$

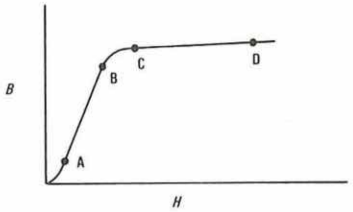
Substituting the given values:

$$f_r = \frac{1}{2\pi}\left(\frac{1}{15 \times 10^{-3} \times 25 \times 10^{-6}} - \frac{10^2}{15^2 \times 10^{-6}}\right)^{\frac{1}{2}},$$

$$= \underline{237\ \text{Hz.}}$$

Q5 *Draw a B/H characteristic of a ferromagnetic material and indicate the "linear" and "saturated" sections of the characteristic.*

A5 The characteristic is shown in the sketch.



The linear section is represented by AB and the saturated section by CD.

Q6 *A 3-phase, 6-pole, 50 Hz induction motor is loaded to operate with a slip of 0·04. Calculate the operating speed.*

A6 The operating speed, n_r, is given by the expression

$$n_r = \frac{f}{p}(1 - s),$$

where f is the frequency of the supply, p is the number of pairs of poles and s is the slip.

$$\text{Thus, } n_r = \frac{50}{3}(1 - 0{\cdot}04) = 16\ \text{r/s},$$

$$= \underline{960\ \text{r/min.}}$$

Q7 *A 240/110 V, 50 Hz transformer has a primary winding of 300 turns. What is the maximum permissible flux in the core?*

A7 The maximum permissible flux in the core, Φ_m, is given by the expression

$$\Phi_m = \frac{E}{4{\cdot}44 f N},$$

where E is the primary voltage, f is the frequency of the supply and N is the number of turns on the primary winding.

$$\text{Thus, } \Phi_m = \frac{240}{4{\cdot}44 \times 50 \times 300} = 3{\cdot}6 \times 10^{-3}\ \text{Wb},$$

$$= \underline{3{\cdot}6\ \text{mWb.}}$$

Q8 *For the DC motor shown in Fig. 3, calculate the supply current I.*

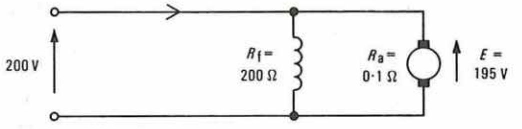


Fig. 3

A8 [Tutorial note: The total current is the sum of the current flowing in the field winding, I_f, and the current flowing in the armature, I_a. I_f is given by the voltage across the field winding (the supply voltage) divided by the resistance of the field winding and I_a is given by the voltage dropped across the armature divided by the resistance of the armature.]

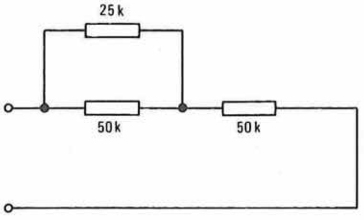
$$I = I_a + I_f = \frac{V}{R_f} + \frac{V - E}{R_a} = \frac{200}{200} + \frac{200 - 195}{0 \cdot 1},$$
$$= \underline{51\ \text{A.}}$$

Q9 In a reverse biased p n junction, describe the effect on the leakage current of increasing the temperature.

A9 The leakage current increases as the temperature is increased because of the greater number of carriers available. The effect is that the leakage current approximately doubles for every 8°C increase in temperature.

Q10 A voltage of 100 V is applied to a circuit comprising two 50 kΩ resistors in series. A voltmeter of internal resistance 25 kΩ is used to measure the voltage across one of the resistors; evaluate the voltmeter indication.

A10 The effective circuit is shown in the sketch.



The resistance, R_i, of the parallel pair of the voltmeter and one 50 kΩ resistor is given by

$$\frac{50 \times 25}{50 + 25} \times 10^3 = 16 \cdot 67\ \text{k}\Omega.$$

Therefore, the indicated voltage, V_i, is given by

$$V_i = \frac{R_i}{R + R_i} \times 100 = \frac{16 \cdot 67}{50 + 16 \cdot 67} \times 100,$$
$$= \underline{25\ \text{V.}}$$

SECTION B

Q11 For the circuit shown in Fig. 4, evaluate

(a) the impedance of the circuit,
(b) the circuit current,
(c) the voltage across the coil,
(d) the voltage across the capacitor, and
(e) the power dissipated by the circuit.

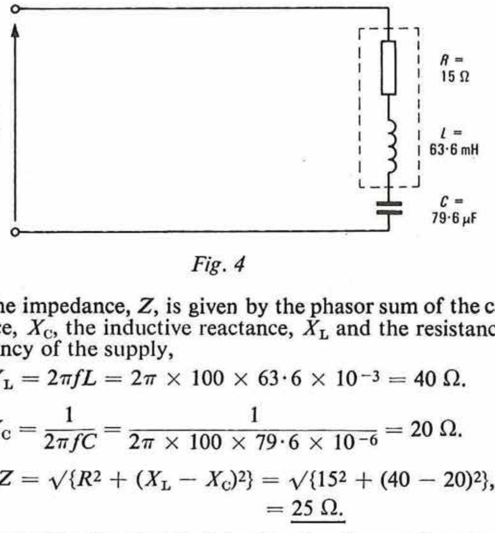


Fig. 4

A11 (*a*) The impedance, Z, is given by the phasor sum of the capacitive reactance, X_C, the inductive reactance, X_L and the resistance. If f is the frequency of the supply,

$$X_L = 2\pi fL = 2\pi \times 100 \times 63 \cdot 6 \times 10^{-3} = 40\ \Omega.$$

$$X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi \times 100 \times 79 \cdot 6 \times 10^{-6}} = 20\ \Omega.$$

$$\therefore \quad Z = \sqrt{\{R^2 + (X_L - X_C)^2\}} = \sqrt{\{15^2 + (40 - 20)^2\}},$$
$$= \underline{25\ \Omega.}$$

(*b*) The current in the circuit, I, is given by the supply voltage, V, divided by the impedance of the circuit, Z; that is,

$$I = V/Z = 200/25 = \underline{8\ \text{A.}}$$

(*c*) The voltage across the coil is given by the current flowing through the coil multiplied by the impedance of the coil (that is, the phasor sum of X_L and R). Therefore, the voltage across the coil is

$$I\sqrt{(R^2 + X_L^2)} = 8\sqrt{(15^2 + 40^2)} = \underline{342\ \text{V.}}$$

(*d*) Similarly to part (*c*), the voltage across the capacitor is

$$IX_C = 8 \times 20 = \underline{160\ \text{V.}}$$

(*e*) Power is only dissipated in the resistor and is equal to

$$I^2R = 64 \times 15 = \underline{960\ \text{W.}}$$

Q12 A 500 V shunt motor has an armature resistance of 0·5 Ω and a field winding resistance of 250 Ω. When loaded to develop a torque of 100 N m, the motor takes a current of 22 A from the supply. Determine the shaft speed.

With the field current remaining unchanged, the motor is further loaded until the torque is 120 N m. Assuming the effect of armature reaction to be negligible, determine the new shaft speed.

A12 The field current, I_f is given by

$$V/R_f = 500/250 = 2\ \text{A},$$

where R_f is the resistance of the field winding and V is the supply voltage.

The armature current, I_a, is given by

$$I - I_f = 22 - 2 = 20\ \text{A},$$

where I is the current drawn from the supply.

The voltage across the armature, E, is given by

$$V - I_aR_a = 500 - (20 \times 0 \cdot 5) = \underline{490\ \text{V.}}$$

If M is the torque developed, then the shaft speed is given by

$$N = \frac{60EI_a}{2\pi M} = \frac{60 \times 490 \times 20}{2\pi \times 100},$$
$$= \underline{936\ \text{r/min.}}$$

When the torque increases to 120 N m, since the armature current is proportional to the torque, the armature current becomes

$$I_a = \frac{120}{100} \times 20 = 24\ \text{A.}$$

The voltage across the armature, E', becomes

$$V - I'_aR_a = 500 - (24 \times 0 \cdot 5) = 488\ \text{V.}$$

The new shaft speed, N', is therefore

$$\frac{60 \times 488 \times 24}{2\pi \times 120} = \underline{932\ \text{r/min.}}$$

Q13 Explain the reason that the current through an inductor cannot change suddenly.

A coil of resistance 100 Ω and inductance 0·5 H is connected to a 25 V DC supply. Evaluate

(a) the final steady state value of current,
(b) the time constant of the circuit,
(c) the instantaneous current after a time equal to the time constant, and
(d) the energy stored in the magnetic field once the current reaches its final steady state.

A13 When a current flows in an inductor, energy is stored in the magnetic field of the inductor. The energy cannot increase or decrease suddenly; therefore, the current cannot change suddenly.

(*a*) If I is the steady state current, V is the voltage across the coil and R is the resistance of the coil,

$$I = V/R = 25/100 = \underline{0 \cdot 25\ \text{A.}}$$

(*b*) If T is the time constant and L the inductance of the coil,

$$T = L/R = 0 \cdot 5/100 = 5 \times 10^{-3}\ \text{s} = \underline{5\ \text{ms.}}$$

(*c*) If i is the instantaneous current at time t,

$$i = I(1 - e^{-\frac{R}{L}t}) = I(1 - e^{-1}) = \underline{0 \cdot 16\ \text{A.}}$$

(*d*) The energy stored in the coil, W_f, is given by

$$W_f = \tfrac{1}{2}I^2L = \tfrac{1}{2} \times 0 \cdot 25^2 \times 0 \cdot 5 = 15 \cdot 6 \times 10^{-3}\ \text{J},$$
$$= \underline{15 \cdot 6\ \text{mJ.}}$$

Q14 *For the network shown in Fig. 5, evaluate the current I and the active power of the coil when terminals A and B of the ideal transformer are*

(*a*) *short circuited,*

(*b*) *open circuited, and*

(*c*) *connected to a 318 μF capacitor.*

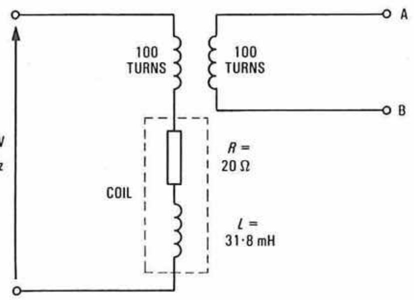


Fig. 5

A14 If X_L is the inductive reactance of the coil, f is the frequency of the supply and L is the inductance of the coil, then

$$X_L = 2\pi fL = 2\pi \times 50 \times 31{\cdot}8 \times 10^{-3} = 10\ \Omega.$$

(*a*) If terminals A and B are short circuited, the reflected load on the primary is 0 and the total primary-circuit impedance, Z, is given by

$$Z = \sqrt{(R^2 + X_L^2)} = \sqrt{(20^2 + 10^2)} = 22{\cdot}4\ \Omega.$$

$$I = V/Z = 110/22{\cdot}4 = \underline{4{\cdot}9\ \text{A}.}$$

$$P = I^2R = 4{\cdot}9^2 \times 20 = \underline{480\ \text{W}.}$$

(*b*) If terminals A and B are open circuited, the reflected load on the primary is infinite. Therefore the current is zero and the active power is zero.

(*c*) The capacitive reactance, X_C, is given by

$$\frac{1}{2\pi fC} = \frac{1}{2\pi \times 50 \times 318 \times 10^{-6}} = 10\ \Omega.$$

Since the transformer has a turns ratio of 1 : 1, the effective primary impedance due to the transformer is 10 Ω capacitive and the total primary circuit impedance, Z, is given by

$$\sqrt{\{R^2 + (X_L - X_C)^2\}} = \sqrt{\{20^2 + (10 - 10)^2\}} = 20\ \Omega.$$

$$I = V/Z = 110/20 = \underline{5{\cdot}5\ \text{A}.}$$

$$P = I^2R = 5{\cdot}5^2 \times 20 = \underline{605\ \text{W}.}$$

Q15 *Explain, with aid of suitable diagrams showing the connections to be made to a cathode-ray oscilloscope, how it may be used to determine the RMS value of an AC sinusoidal signal derived from equipment fed from an AC mains supply. Your explanation should include reference to appropriate precautions.*

An oscilloscope is used to display a sinusoidal alternating voltage. The display is shown in Fig. 6. The Y-amplifier sensitivity is set to 5 V/cm and the X-amplifier sensitivity to 100 μs/cm. Determine the RMS value and the frequency of the voltage.

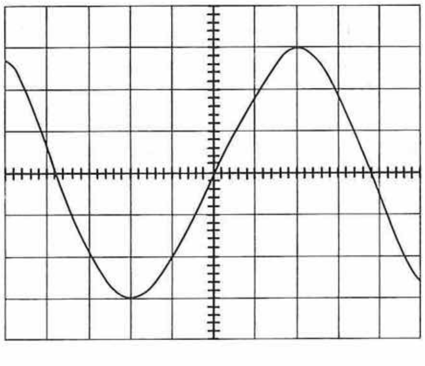


Fig. 6

A15 [*Tutorial note:* There are many methods of answering the first part of this question. The answer should demonstrate the following main points:

(*a*) The diagram should clearly show the connections to the oscilloscope.

(*b*) The accompanying explanation should make clear the awareness of the problem that part of the test circuit can be short circuited by the oscilloscope connections and that the circuit illustrated avoids such difficulties.

(*c*) The interpretation of the display should indicate the division of the peak-to-peak measurement by $2\sqrt{2}$ in order to obtain the RMS value, not forgetting reference to the dial settings of the oscilloscope.]

The RMS voltage, V, is given by $\dfrac{V_{\text{pp}}}{2\sqrt{2}}$, where V_{pp} is the peak-to-peak voltage.

$$\therefore \quad V = \frac{6 \times 5}{2\sqrt{2}} = \underline{10{\cdot}6\ \text{V}.}$$

The period of the waveform, T, is $7{\cdot}6 \times 100 \times 10^{-6}$ s.

Therefore, the frequency is $\dfrac{1}{T} = \underline{1316\ \text{Hz}.}$

Q16 *Draw the forward anode current/anode voltage characteristic of a thyristor for various values of gate current.*

Answer any TWO *of the following:*

(*a*) *Three coils of resistance 12 Ω and reactance 16 Ω are connected in delta to a 415 V, 3-phase, 50 Hz supply. Evaluate*

(*i*) *the phase currents,*
(*ii*) *the line currents,*
(*iii*) *the total active power, and*
(*iv*) *the total apparent power.*

(*b*) *Explain, with the aid of sketches, why the rotor of a 3-phase induction motor rotates in the same direction as the rotating magnetic field set up by the stator windings.*

(*c*) *A magnetic circuit is shown in Fig. 7 and is of uniform cross-sectional area throughout. The magnetic characteristic of the core material is given in Fig. 8, the material being steel plate. Estimate the current in the coil to produce a flux density of 1·2 T in the air gap, assuming that all the flux is set up within the magnetic circuit.*

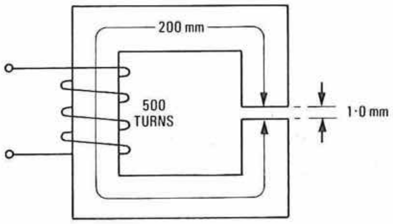


Fig. 7

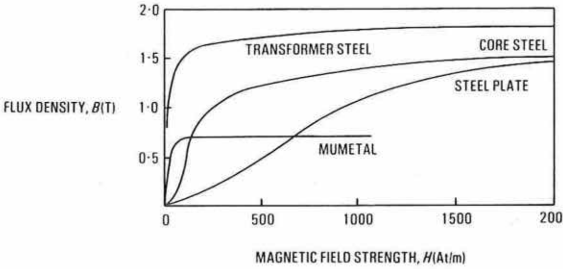


Fig. 8

MATHEMATICS III 1981

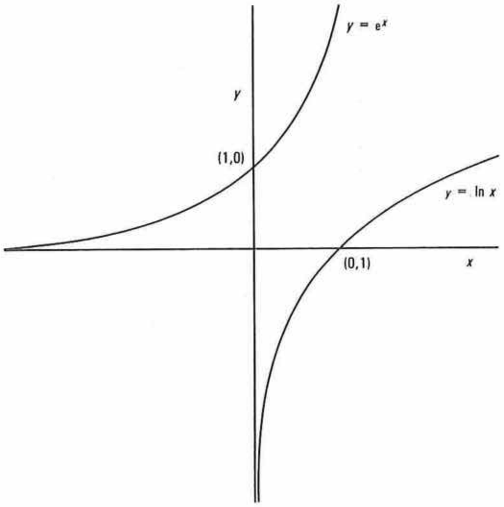
Students were expected to attempt all questions in section A and 4 questions in section B. This was a 3 h examination

The Boolean function *A and B* can be written either as AB or as $A.B$. The notation used throughout this paper (AB) was that used in the examination paper.

SECTION A

Q1 *Sketch on the same diagram the graphs of* $y = e^x$ *and* $y = \ln x$*. What is the relationship between the 2 graphs?*

A1 The 2 graphs are shown in the sketch. Each graph is the reflection of the other in the line $y = x$.



Q2 *Evaluate* $200 \ln \frac{V_1}{V_2}$ *when* $V_1 = 7{\cdot}46$ *and* $V_2 = 6{\cdot}38$.

A2

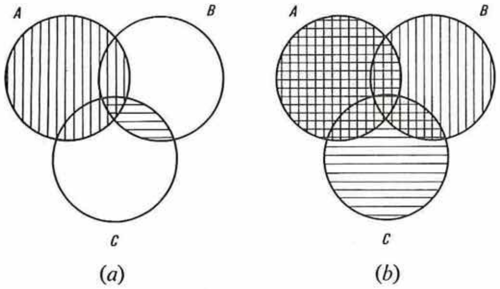
$$\begin{aligned} 200 \ln \frac{V_1}{V_2} &= 200 \ln \frac{7{\cdot}46}{6{\cdot}38}, \\ &= 200 \ln 1{\cdot}17, \\ &= 200 \times 0{\cdot}156, \\ &= \underline{31{\cdot}3.} \end{aligned}$$

Q3 *Use Venn diagrams to illustrate that* $A + BC = (A + B)(A + C)$.

A3 In sketch (*a*), A is shaded vertically and BC is shaded horizontally. $A + BC$ is the total shaded area.

In sketch (*b*), $A + B$ is shaded vertically and $A + C$ is shaded horizontally. $(A + B)(A + C)$ is the doubly-shaded area.

Therefore, $A + BC = (A + B)(A + C)$, because the total shaded area in sketch (*a*) coincides with the doubly-shaded area in sketch (*b*).



(*a*) (*b*)

Q4 *Obtain in the form* $x + jy$ *the sum of the phasors* $3\angle 40°$ *and* $4\angle 130°$*, giving* x *and* y *correct to 2 decimal places.*

A4

$$\begin{aligned} 3\angle 40° &= 3 \cos 40° + \mathrm{j}3 \sin 40°, \\ &= 2{\cdot}298 + \mathrm{j}1{\cdot}928. \\ 4\angle 130° &= 4 \cos 130° + \mathrm{j}4 \sin 130°, \\ &= -\,2{\cdot}571 + \mathrm{j}3{\cdot}064. \\ \therefore \quad 3\angle 40° + 4\angle 130° &= -\,0{\cdot}273 + \mathrm{j}4{\cdot}992, \\ &= \underline{-\,0{\cdot}27 + \mathrm{j}4{\cdot}99,} \end{aligned}$$

correct to 2 decimal places.

Q5 *Differentiate:*

(*a*) $2x^4 - 3x^2 + 5$;

(*b*) $4 \cos \frac{1}{2}\theta$; *and*

(*c*) $8\sqrt{t}$.

A5 (*a*)

$$\frac{\mathrm{d}}{\mathrm{d}x}(2x^4 - 3x^2 + 5) = \underline{8x^3 - 6x.}$$

(*b*)

$$\frac{\mathrm{d}}{\mathrm{d}\theta}(4 \cos \tfrac{1}{2}\theta) = \underline{-\,2 \sin \tfrac{1}{2}\theta.}$$

(*c*)

$$\begin{aligned} 8\sqrt{t} &= 8t^{1/2}. \\ \frac{\mathrm{d}}{\mathrm{d}t}(8\sqrt{t}) &= \frac{8}{2}t^{\,-1/2}, \\ &= \underline{4t^{-1/2}}. \end{aligned}$$

Q6 *A mechanism rotates through an angle* θ *radians in* t *seconds, where* $\theta = 2 + 50t - 2t^3$*. Find the angular velocity after 2 s*

(*a*) *in radians per second, and*

(*b*) *in revolutions per minute.*

A6 (*a*)

$$\begin{aligned} \text{Angular velocity} &= \frac{\mathrm{d}\theta}{\mathrm{d}t}, \\ &= 50 - 6t^2, \\ &= 50 - 24, \\ &= \underline{26 \text{ rad/s.}} \end{aligned}$$

(*b*) The angular velocity in revolutions per minute

$$\begin{aligned} &= \frac{26}{2\pi} \times 60, \\ &= \underline{248 \text{ r/min.}} \end{aligned}$$

Q7 *The cylindrical shaft of diameter 30 mm shown in Fig. 1 has 2 parallel flats at its end, each of width 20 mm. Calculate the perpendicular distance between the flats.*

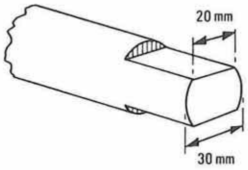
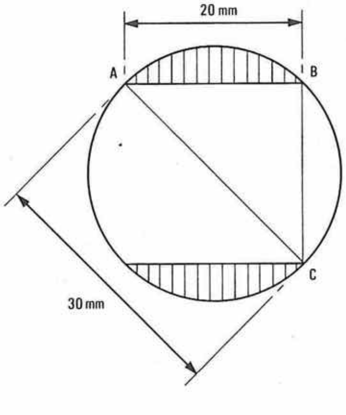


Fig. 1

A7 The sketch shows the end view of the shaft. In the sketch, AB = 20 mm, and AC = 30 mm.

Hence, by Pythagoras' Theorem, the distance between the flats, BC,

$$\begin{aligned} &= \sqrt{(30^2 - 20^2)}, \\ &= \sqrt{(900 - 400)}, \\ &= \sqrt{500}, \\ &= \underline{22{\cdot}4 \text{ mm.}} \end{aligned}$$



SECTION B

Q8 The current i milliamps at time t seconds is given by the equation $i = 10\cos(100\pi t - \pi/10)$.

(*a*) *Tabulate values of i for values of t between 0 ms and 10 ms at 2 ms intervals.*

(*b*) *Plot the graph of i against t using these tabulated values.*

(*c*) *State the smallest positive value of t for which i is zero.*

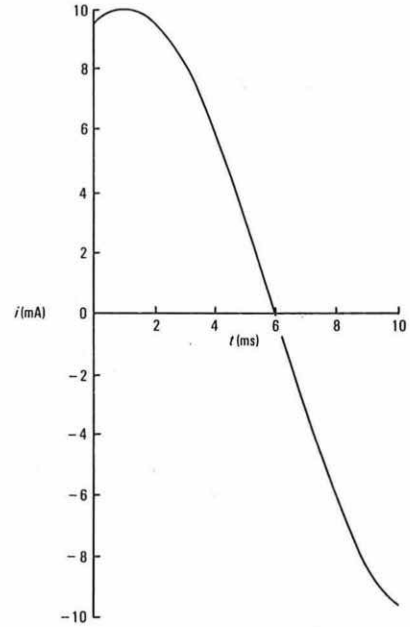
(*d*) *State the maximum value of i and obtain the smallest positive value of t for which this maximum occurs.*

(*e*) *State the period.*

A8 (*a*)

t (ms)	0	2	4	6	8	10
$100\pi t - \pi/10$	$-\pi/10$	$\pi/10$	$3\pi/10$	$\pi/2$	$7\pi/10$	$9\pi/10$
i (mA)	9·51	9·51	5·88	0	−5·88	−9·51

(*b*)



(*c*) 0·006 s (or 6 ms).

(*d*) The maximum value of i is 10 mA and it occurs when $t = 0{\cdot}001$ s (or 1 ms).

(*e*) The period is 20 ms.

Q9 (*a*) *Differentiate:*

(*i*) $i = 3\sin(100\pi t - \pi/4)$,
(*ii*) $y = (2x+1)(x^2-3)$, *and*
(*iii*) $z = \sqrt{(x^2+1)}$.

(*b*) *The graph in Fig. 2 (which was provided as a worksheet) shows the charge q coulombs on a capacitor t seconds after the capacitor has started to discharge.*

(*i*) *By drawing a suitable tangent, find the value of the current* $\frac{dq}{dt}$ *when* $t = 4$.

(*ii*) *State the initial charge* q_0, *the charge* q_1 *after 4 s and the charge* q_2 *after 8 s. Show that the ratio* $q_1{:}q_0$ *is approximately the same as the ratio* $q_2{:}q_1$.

A9 (*a*) (*i*)

$$\frac{di}{dt} = 3 \times 100\pi\cos(100\pi t - \pi/4),$$
$$= \underline{300\pi\cos(100\pi t - \pi/4).}$$

(*ii*)

$$y = 2x^3 + x^2 - 6x - 3.$$
$$\frac{dy}{dx} = \underline{6x^2 + 2x - 6.}$$

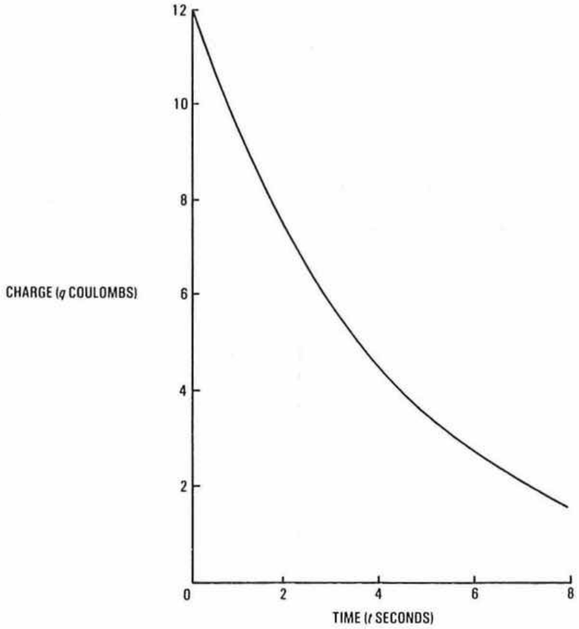
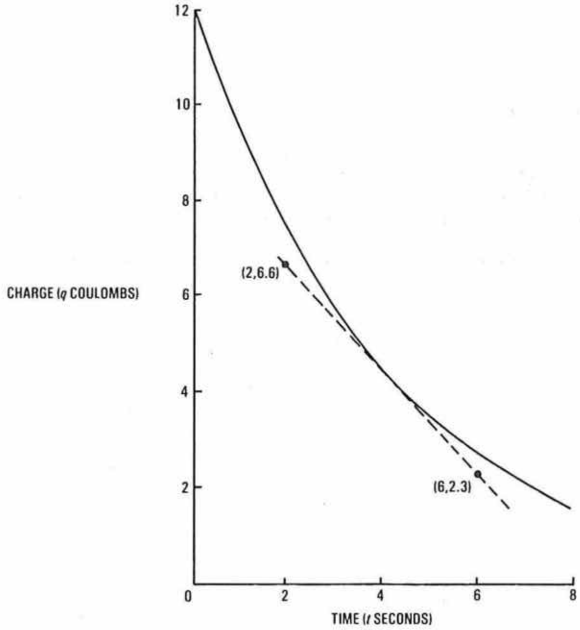


Fig. 2

(*iii*) $z = u^{1/2}$, where $u = x^2 + 1$.

$$\frac{dz}{dx} = \frac{dz}{du} \times \frac{du}{dx},$$
$$= \tfrac{1}{2}u^{-1/2} \times 2x,$$
$$= \underline{\frac{x}{\sqrt{(x^2+1)}}}.$$

(*b*) (*i*) The tangent is shown in the sketch as a dashed line.



The co-ordinates (2, 6·6) and (6, 2·3) lie on the tangent. The gradient of the tangent at $t = 4$ is given by

$$\frac{2{\cdot}3 - 6{\cdot}6}{6 - 2},$$
$$= \frac{-4{\cdot}3}{4},$$
$$= -1{\cdot}1.$$

Therefore, the current is $\underline{-1{\cdot}1\text{ A.}}$

(ii) $q_0 = 12, q_1 = 4\cdot5$, and $q_2 = 1\cdot6$.

$\therefore \quad q_1{:}q_0 = 0\cdot37$, and $q_2{:}q_1 = 0\cdot35$.

These ratios are approximately equal.

Q10 *(a) (i) Show that* $\overline{\overline{A} + \overline{B}} = AB$.
(ii) By using a similar formula show how the function $A + B$ *can be realised if the only gates available are* NAND *and* NOT *gates.*

(b) Using a Karnaugh map, or otherwise, simplify as far as possible the logic function $f = \overline{X}Y\overline{Z} + XYZ + \overline{X}YZ + XY\overline{Z}$.

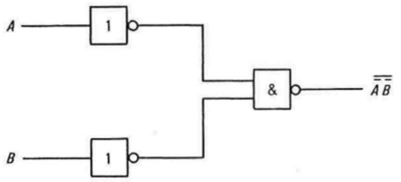
(c) Simplify the logic functions $ABC + AB\overline{C}$ *and* $A\overline{B}D + A\overline{B}\overline{D}$. *Hence simplify, as far as possible, the logic function*

$$g = ABC + AB\overline{C} + ABD + A\overline{B}D + A\overline{B}\overline{D}.$$

A10 *(a) (i)* $\overline{\overline{A} + \overline{B}} = \overline{\overline{A}}\,\overline{\overline{B}} = \underline{AB.}$

(ii) $A + B = \overline{\overline{A}\,\overline{B}}.$

The sketch shows how NAND and NOT gates can be used to realise $A + B$.



(b) The sketch shows the Karnaugh map of *f*. From the map it can be seen that $f = Y$.

Z \ XY	00	01	11	10
0		×	×	
1		×	×	

(c)

$$ABC + AB\overline{C} = AB(C + \overline{C}) = AB.$$
$$A\overline{B}D + A\overline{B}\overline{D} = A\overline{B}(D + \overline{D}) = A\overline{B}.$$

Hence,

$$\begin{aligned} g &= AB + ABD + A\overline{B}. \\ &= AB + A\overline{B} \text{ (law of absorption)}, \\ &= A(B + \overline{B}), \\ &= \underline{A.} \end{aligned}$$

Q11 *(a) (i) Copy and complete the following table:*

x	*0*	*0·2*	*0·4*	*0·8*	*1·2*
$y = 0\cdot4e^{3x}$					

(ii) Plot these points on the semi-logarithmic graph paper provided.
(iii) From your graph read off the value of y when $x = 1\cdot6$ *and the value of x for which* $y = 1\cdot6$.

(b) WITHOUT USING A CALCULATOR *estimate to one significant figure the value of*

$$\frac{\sqrt{63\cdot2} \times 540}{0\cdot887 \times 3\cdot93^2}.$$

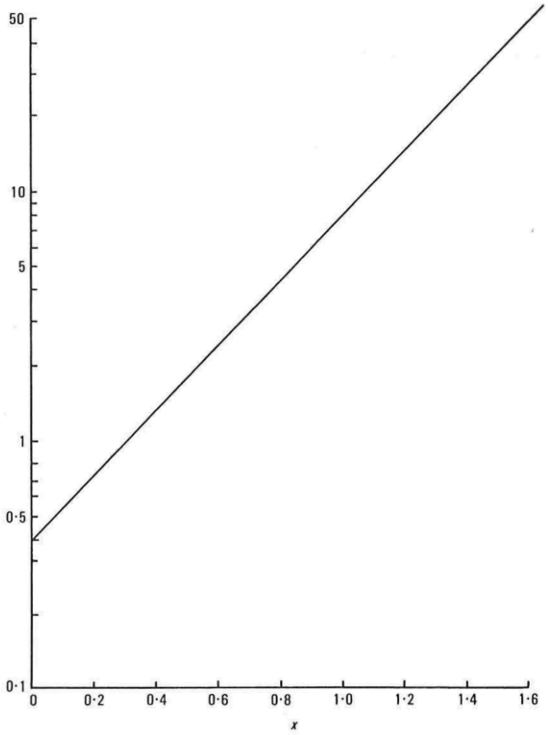
All steps in your estimation must be clearly shown.

A11 *(a) (i)*

x	0	0·2	0·4	0·8	1·2
y	0·4	0·73	1·33	4·41	14·64

(ii) See sketch.

(iii) When $x = 1\cdot6$, $y = 48$ (or 49).
When $y = 1\cdot6$, $x = 0\cdot47$ (or 0·46).



(b)

$$\begin{aligned} \text{Value} &= \frac{\sqrt{64} \times 540}{0\cdot9 \times 4^2}, \\ &= \frac{8 \times 540}{0\cdot9 \times 16}, \\ &= \frac{1 \times 540}{0\cdot9 \times 2}, \\ &= \frac{540}{1\cdot8}, \\ &= \underline{300.} \end{aligned}$$

[*Tutorial note:* Any reasonable series of approximations would be acceptable.]

Q12 *(a) Find the co-ordinates of the turning points on the curve* $y = 2x^3 - 3x^2 - 12x$ *and determine their nature. Sketch the curve.*

(b) The truth table for the function f is as shown.

A	*B*	*f*
0	0	1
0	1	1
1	0	1
1	1	0

Write down an expression for the function $\overline{f}$ *and hence, or otherwise, show that f can be realised using a single gate.*

A12 *(a)*

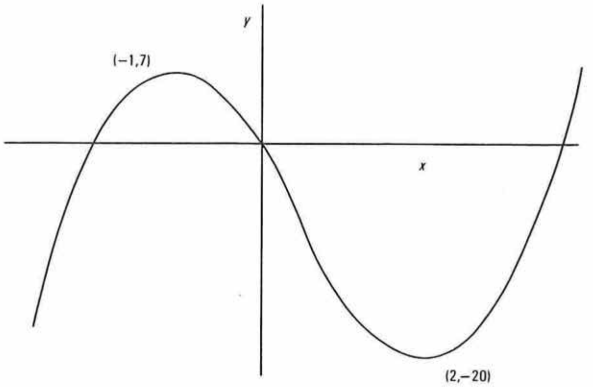
$$\begin{aligned} \frac{dy}{dx} &= 6x^2 - 6x - 12, \\ &= 6(x^2 - x - 2), \\ &= 6(x - 2)(x + 1). \end{aligned}$$

Turning points occur when $\frac{dy}{dx} = 0$;

that is, at $x = -1$ ($y = -2 - 3 + 12 = 7$),
and $x = 2$ ($y = 16 - 12 - 24 = -20$).

	$x < -1$	$-1 < x < 2$	$2 < x$
$x + 1$	−	+	+
$x - 2$	−	−	+
$\frac{dy}{dx}$	+ /	− \	+ /

$(-1, 7)$ is a local maximum, and $(2, -20)$ is a local minimum.
When $x = 0$, $y = 0$.
When $x \rightarrow +\infty$, $y \rightarrow +\infty$.
When $x \rightarrow -\infty$, $y \rightarrow -\infty$.
The curve is sketched below.



(*b*) $\bar{f} = AB.$

$f = \overline{AB}.$

Therefore, f can be realised by using a NAND gate.

Q13 *A closed rectangular tank has a volume of 9 m*^{3} *and its length is twice its width.*

(*a*) *Obtain a formula for the height h metres, in terms of the width w metres.*

(*b*) *Show that the outer surface area, A square metres, is given by the formula*

$$A = 4w^2 + \frac{27}{w}.$$

(*c*) *Find the value of w for which A is minimal and show that this minimum value of A is 27 m*^{2}*.*

(*d*) *What would be the volume of a spherical tank with outer surface area 27 m*^{2}*?*

$$\left[\textit{For a sphere } S = 4\pi r^2,\ V = \frac{4\pi r^3}{3}.\right]$$

A13 (*a*) Volume $= h \times w \times 2w.$

Hence, $2w^2h = 9.$

$$\therefore \quad \underline{h = \frac{9}{2w^2}.}$$

(*b*)

$$\begin{aligned} A &= 2(2w \times w + 2w \times h + w \times h), \\ &= 2(2w^2 + 3wh), \\ &= 4w^2 + 6w \times \frac{9}{2w^2}, \\ &= 4w^2 + \frac{27}{w}. \end{aligned}$$

QED

(*c*)

$$\begin{aligned} \frac{dA}{dw} &= 8w - \frac{27}{w^2}, \\ &= \frac{8w^3 - 27}{w^2}. \end{aligned}$$

$\frac{dA}{dw} = 0$ when $8w^3 - 27 = 0,$

that is, when $w^3 = \frac{27}{8},$

and $w = \frac{3}{2}.$

When $w < \frac{3}{2}, \frac{dA}{dw} < 0$; when $w > \frac{3}{2}, \frac{dA}{dw} > 0.$

Hence $w = \frac{3}{2}$ gives a minimum value of A.

$$\begin{aligned} \text{Minimum value of } A &= 4 \times \left(\frac{3}{2}\right)^2 + \frac{27}{3/2}, \\ &= 9 + 18, \\ &= \underline{27\ \text{m}^2.} \end{aligned}$$

(*d*) $4\pi r^2 = 27.$

$$\begin{aligned} \therefore \quad r &= \sqrt{\left(\frac{27}{4\pi}\right)}, \\ &= 1{\cdot}466\ \text{m}. \\ V &= \frac{4\pi}{3} \times 1{\cdot}466^3, \\ &= \underline{13{\cdot}2\ \text{m}^3.} \end{aligned}$$

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Published by *British Telecommunications Engineering Journal*, 2–12 Gresham Street, London EC2V 7AG
and printed in Great Britain by Unwin Brothers Limited, Old Woking, Surrey.